Nonlinear wave methods for examination of damage in materials are the new frontier of acoustical nondestructive testing, offering previously unimagined sensitivity, speed of application, and ease of interpretation, as Paul Johnson reveals

The new wave in acoustic testing

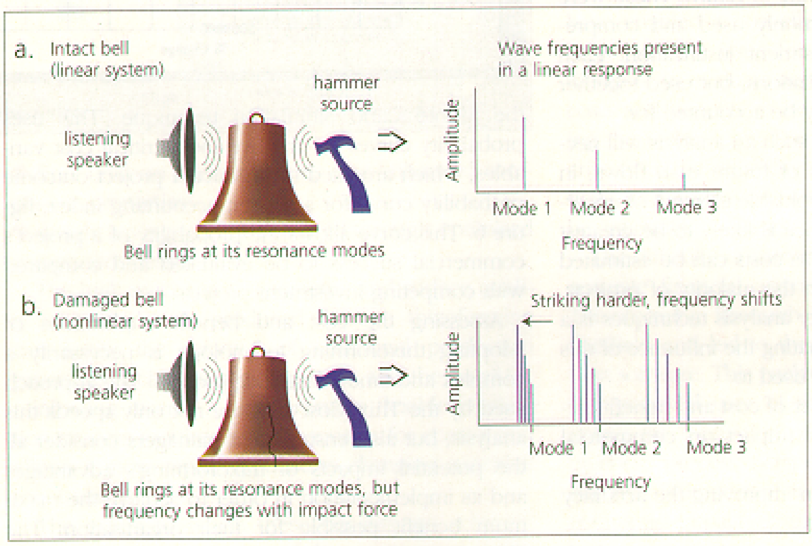


Figure 1

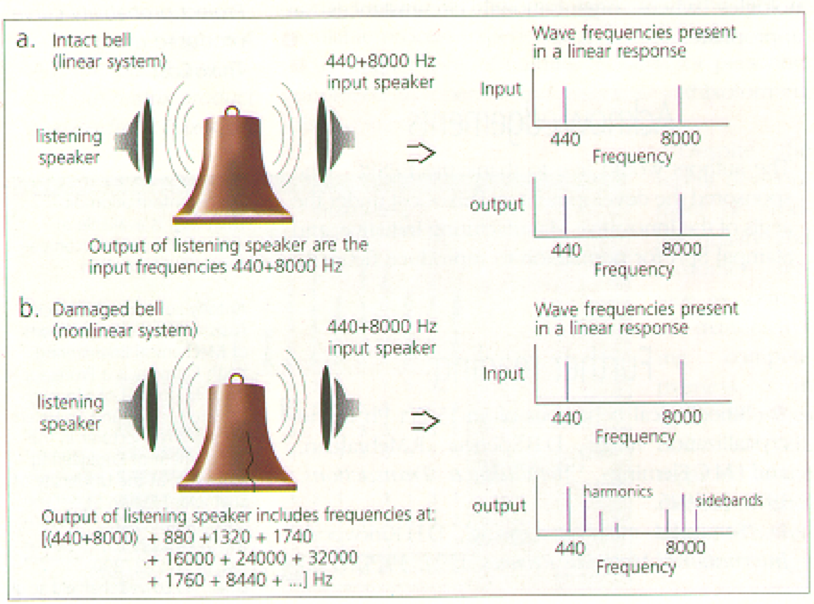
Illustration of linear versus nonlinear wave resonance behaviour in a bell

Figure 2

Illustration of linear versus nonlinear wave harmonics and modulation response in a bell

Strike a bell, and the bell rings at its resonance modes. Strike it harder and the bell rings at the same tone, only louder. Now imagine a small crack in the bell, perhaps invisible to the eye. We strike the bell gently and it rings normally. Striking it harder we find, to our surprise, that the tone drops in frequency ever so slightly. Striking it even harder, the tone drops even further down in frequency. This frequency shift is a manifestation of nonlinearity due to the presence of the crack.

Figure 1 illustrates how the bell responds elastically linearly when undamaged, but elastically nonlinearly when damaged. The bell behaves in an expected manner when intact, figure 1a – ringing the bell with a hammer excites the resonance modes of the bell, giving rise to a frequency spectrum in which only the resonance modes are present. If the bell has even a very small crack present, the modal frequencies depend on how hard the bell is struck, figure 1b. This is a nonlinear effect – a change in wave frequency with wave amplitude. We have called this method nonlinear resonant ultrasound spectroscopy (NRUS), a subset of nonlinear elastic wave spectroscopy (NEWS).



This example is taken a step further in figure 2 for the sake of illustrating additional manifestations of nonlinearity. For instance, we input 440 Hz and 8000 Hz into the undamaged bell using an audio speaker (these are arbitrarily chosen frequencies and are not crucial to the general result). Not suprisingly, the bell will ring at the two input frequencies, figure 2a. If we input the two tones into the bell when a small crack is present, interesting things happen again. We find that, not only does the bell ring at 440 Hz and 8000 Hz, but other frequencies abound, figure 2b. We also detect harmonics at two times, three times and four times each input frequency (880, 1320, and 1740 Hz; and 16000, 24000, and 32000 Hz, respectively). In addition, we detect the sum and difference frequencies between the 440 and 8000 Hz, or sidebands, of 8000±440 Hz. This method is known as nonlinear wave modulation spectrscopy (NWMS), another subset of NEWS.

The nonlinearity due to the presence of one or more cracks is an extremely sensitive indicator of the presence of damage. The undamaged portion of the sample produces nearly zero nonlinear effect. The damaged portion of the material acts as a nonlinear mixer (multiplier). It is a localised effect. Using a frequency spectrum analysis, we can easily tell the difference between an undamaged and damaged object. In fact, I am not aware of a more sensitive, more rapid, easy -to-apply method for detecting and examining material damage.

In our studies we have found that the nonlinear response of a sample provides a quick, qualitative test of pass/fail in numerous metal components such as alternator housings, engine bearing caps, various